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Title: **Nonlinear Signal Processing Schemes for Robust Target Detection in Radar**

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I. Executive Summary

In detection, the interference due to clutter or jamming can severely deteriorate the quality of the received signal to the point of concealing the target. The objective of this investigation is to improve detection in high density clutter or jamming by using nonlinear signal processing in conjunction with frequency diverse techniques. In particular, analysis and experimental studies have been concerned with the application of Order Statistic (OS) processing and Split Spectrum Processing (SSP) to detect target signals corrupted by strong clutter. The study of OS processing is also extended to morphological processors to improve signal-to-noise ratio (SNR) and feature extraction for recognition and classification. These studies have applications in radar, ultrasound, sonar, and imaging where clutter is the primary limiting factor.

Linearly Combined Order Statistic CFAR Detector

Adaptive detection techniques have been investigated using OS as a method of characterizing the clutter and estimating the threshold for CFAR detection. In particular, Linearly Combined Order Statistic (LCOS) CFAR detectors are examined for efficient and robust threshold estimation applied to exponentially-distributed background observations for improved detection. Two optimization philosophies have been employed to determine the weighting coefficients of the order statistics. The first method optimizes the coefficients to obtain efficient estimates of clutter referred to as the Censored Maximum Likelihood (CML) and Best Linear Unbiased (BLU) CFAR detectors. The second optimization involves maximizing the probability of detection under Swerling II targets and is referred to as the Most Powerful Linear (MPL) CFAR detector. The BLU-CFAR detector assumes no knowledge of the target distribution in contrast to the MPL-CFAR detector which requires partial knowledge of the target distribution. The design of these CFAR detectors and the probability of detection performance are mathematically analyzed for background observations having homogeneous and heterogeneous distributions wherein the trade-offs between robustness and detection performance are illustrated.

OS-CFAR Threshold Estimators for Ultrasonic Flaw Detection

As an application, adaptive ultrasonic flaw detection has been investigated utilizing frequency diverse order statistic filtering followed by order statistic based constant false alarm rate (CFAR) target detection. Frequency diverse OS filtering is intended to improve the target signal-to-clutter

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ratio. A theoretical analysis of the rank order has been developed specifying the optimal rank that will maximize the probability of detection. When the target signal has low SNR, it has been shown that higher ranks (median through maximum) exhibit robust performance. Lower ranks (minimum, ...), although they may perform well for certain target and clutter distributions, often fail to detect target signals when inconsistencies exist in the distribution of observations (e.g., null observations). The theoretical analysis has been confirmed with computer simulation when target and clutter have Rayleigh and Weibull distributions.

The effect of null observations has also been verified using frequency diverse ultrasonic experimental results. Adaptive order statistic detection methods that were studied included order statistic (OS-CFAR) and trimmed mean (TM-CFAR) for threshold estimations utilizing local statistics of clutter. OS-CFAR and TM-CFAR threshold estimators censor outliers resulting in a more robust performance when compared with the cell averaging (CA-CFAR) method. These methods have been evaluated using ultrasonic experimental data in the presence of high signal scattering. It has been shown that OS-CFAR and TM-CFAR outperform CA-CFAR when the range cell used for the threshold estimate contains outliers.

Morphological Filters for Improved Detection

The analysis of the OS filter has been extended to morphological filters. Morphological filters are a class of nonlinear operations based on set theory. Both statistical and deterministic properties of these filters are being evaluated in the context of using different structuring elements. Furthermore, statistical properties of sequential morphological operations have been studied using explicit solutions for special cases, and Monte Carlo simulation when the structure of morphological operations is complex. This study enables us to evaluate the noise suppression and biasing effects of morphological filters and will lead to the design of filters that can extract target signatures in high clutter environments. The signal-to-noise ratio enhancement of morphological filters is also compared with that of recursive median filters and ensemble averaging using ultrasonic flaw echoes masked by clutter. Results indicate that morphological filters perform better than recursive median filters in preserving the geometrical structure of the signal and can replace ensemble averaging which requires numerous measurements.

Application of Wavelet Transform Techniques for Target Detection

Work also has been initiated in target detection using wavelet transform techniques in conjunction with the frequency diversity techniques (i.e., split-spectrum processing) developed in earlier work for clutter reduction. The wavelet transform technique is used to perform the spectral decomposition, prior to utilization of various nonlinear algorithms for target detection in high density clutter. The wavelet transform, which is based on the principle of constant-Q or constant relative bandwidth frequency, is widely used for the analysis of non-stationary signals. Experimental results obtained with the constant-Q SSP (split-spectrum processing) technique indicates improved performance in identifying and extracting multiple targets compared to the conventional fixed bandwidth SSP.

Detection and Resolution of Multiple Targets UsingTime-Frequency and Deconvolution Techniques

The split spectrum processing (SSP) technique, which is based on the frequency diversity principle, has been used effectively to suppress clutter when a single target is present. However, in general, more than one target may exist over the resolution cell, resulting in interference which can mask one or more of the targets and present difficulties in their detection and identification. It has been shown in this work that the inter-target interference between two targets exhibits strong variation with frequency. Therefore, by bandpass filtering the input signal at different center frequencies, it is possible to obtain an output signal which exhibits less interference between the adjacent targets compared to the original wideband signal. The simulation and experimental results show that by utilizing such bandpass signals, constant bandwidth and constant Q SSP algorithms can yield both signal-to-noise ratio enhancement (SNRE) and resolution improvement.

Deconvolution techniques have been widely used to improve the resolution and quality of ultrasonic images. However, deconvolution techniques require a priori information about the system, which presents the main difficulty in their implementation. In this work, the Split Spectrum Processing (SSP) spectral histogram technique is utilized to estimate the system transfer function. The spectral histogram technique is based on the statistics of narrowband signals selected by the absolute-minimization operation. Theoretical analysis indicates that the spectral histogram is similar in nature to the Wiener filter transfer function and can therefore be used to estimate the optimal frequency region for L1 deconvolution. The theoretical and experimental results indicate that the proposed technique provides enhancement in identifying and extracting multiple targets.

Publications Resulting from ONR Grant Support (1992 -1994):

1. M.A. Mohamed and J. Saniie, "Ultrasonic Signal Enhancement Using Order Statistic and Morphological Filters", by, Review of Progress in QuantitativeNondestructive Evaluation, Vol. 11A, pp. 943-950, Plenum Press, 1992.

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14. J. Xin and N. M. Bilgutay, "Detection and Resolution of Multiple Targets Using Time-Frequency Techniques," 1994 IEEE Ultrasonics Symposium, November 1-4, 1994, Cannes, France.

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18. D. T. Nagle and J. Saniie, "Asymptotic Analysis of OS-CFAR Detectors for General Clutter Distributions," IEEE Transactions on Aerospace Electronic Systems, (in review).

19. K. Donohue, Y. Guez and N. M. Bilgutay, "A Neural Network Architecture for Ultrasonic Flaw Detection," IEEE Transactions on Signal Processing (in review).

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2. Greg Maskarinec, Research Asst. Prof., Drexel University
3. D. T. Nagle, Postdoctoral Fellow, IIT
4. M. Mohamed, , Postdoctoral Fellow, IIT

Ph.D. Theses Completed/Supported by ONR Grant:

1. Rashmi Murthy (July, 1992): Statistical Characterization of Frequency Diverse Ultrasonic Signals, Ph.D. Thesis, Department of Electrical & Computer Engineering, Drexel University.

2. M. A. Mohamed (December 1992): Properties of Morphological Filters and Their Applications in Ultrasonic Imaging, Ph.D. Thesis, Department of Electrical & Computer Engineering, Illinois Institute of Technology.

3. Jian-qiang Xin (May, 1994): Detection and Resolution of Multiple Targets Using Time-Frequency and Deconvolution Techniques, Ph.D. Thesis, Department of Electrical & Computer Engineering, Drexel University.

4. X. Jin (August 1994): Spectral Analysis for Ultrasonic Nondestructive Evaluation, Ph.D. Thesis, Department of Electrical & Computer Engineering, Illinois Institute of Technology.

Other Graduate Students Supported by ONR Grant

1. K. K. Chin (Ph.D. student IIT)
2. M. Malik (Ph.D. student IIT)
3. M. Unluturk (Ph.D. student IIT)

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